

**UNITED STATES DISTRICT COURT  
FOR THE EASTERN DISTRICT OF WISCONSIN**

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ALVIN BALDUS, CINDY BARBERA,  
CARLENE BECHEN, ELVIRA BUMPUS,  
RONALD BIENSDEIL, LESLIE W. DAVIS III,  
BRETT ECKSTEIN, GLORIA ROGERS,  
RICHARD KRESBACH, ROCHELLE MOORE,  
AMY RISSEEUW, JUDY ROBSON, JEANNE  
SANCHEZ-BELL, CECELIA SCHLIEPP, and  
TRAVIS THYSSEN, RON BOONE, VERA BOONE,  
EVANJELINA CLEERMAN, SHEILA COCHRAN,  
MAXZINE HOUGH, CLARENCE JOHNSON,  
RICHARD LANGE, and GLADYS MANZANET,

Plaintiffs,

TAMMY BALDWIN, GWENDOLYNNE MOORE,  
and RONALD KIND,

Intervenor-Plaintiffs,

v.

Case No. 11-CV-562  
JPS-DPW-RMD

Members of the Wisconsin Government Accountability  
Board, each only in his official capacity:  
MICHAEL BRENNAN, DAVID DEININGER,  
GERALD NICHOL, THOMAS CANE,  
THOMAS BARLAND, TIMOTHY VOCKE and  
KEVIN KENNEDY, Director and General Counsel for the  
Wisconsin Government Accountability Board,

Defendants,

F. JAMES SENSENBRENNER, JR., THOMAS E. PETRIS,  
PAUL D. RYAN, JR., REID J. RIBBLE, and SEAN P. DUFFY,

Intervenor-Defendants.

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VOCES DE LA FRONTERA, INC., RAMIOR VARA,  
OLGA VARA, JOSE PEREZ, and ERICA RAMIREZ,

Plaintiffs,

v.

Case No. 11-CV-1011  
JPS-DPW-RMD

Members of the Wisconsin Government Accountability Board, each only in his official capacity:  
MICHAEL BRENNAN, DAVID DEININGER,  
GERALD NICHOL, THOMAS CANE,  
THOMAS BARLAND, TIMOTHY VOCKE and  
KEVIN KENNEDY, Director and General Counsel for  
the Wisconsin Government Accountability Board,

Defendants.

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**ERIK V. NORDHEIM**  
**Expert Disclosures— Fed. R. Civ. P. 26(a)(2)(B)**

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STATE OF WISCONSIN       )  
  ) SS  
COUNTY OF DANE        )

Erik V. Nordheim being duly sworn on oath deposes and says:

1. I am an adult and reside in Madison, Wisconsin. My qualifications and list of publications are contained in my curriculum vitae attached as exhibit A.
2. My written report is attached as exhibit B. This report contains the opinions and the bases for the opinions I will be expressing in this matter. It also contains the exhibits used to summarize or support the report.
3. The report is given under oath. All expressed opinions are to a reasonable probability grounded on sound statistical practice based upon my training and experience. The data relied upon are typical of the data relied upon by professional statisticians in making statistical analyses in matters of this nature.

4. I have not testified in a court proceeding or in a deposition in the last four years.
5. I am being compensated at the rate of \$175.00 per hour for my work in this matter.

Erik V Nordheim  
ERIK V. NORDHEIM

Signed and sworn before me  
this 14 day of December 2011.

James A. Olson  
Notary Public, State of Wisconsin  
My Commission Expires: permanently

December 2011

## CURRICULUM VITAE FOR ERIK V. NORDHEIM

Erik V. (Rick) Nordheim

Professor

Department of Statistics

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### EDUCATION

Ph.D. University of Minnesota, School of Statistics (1973-1977; degree granted June 1978)  
Thesis: *Inference from nonrandomly missing data*. University of Minnesota,  
235 pp.

M.A. University of California, Berkeley, Department of Physics (1967-1972)

B.A. University of California, Berkeley, Department of Physics (1964-1966)

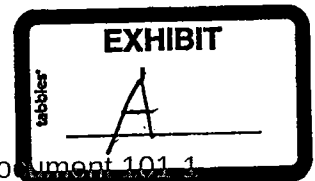
University of California, Santa Barbara (Administrative Center for Education

Abroad Program, Goettingen, West Germany) (1963-1964)

University of California, Riverside (1961-1963)

### POSITIONS HELD

1988-Present	Full Professor, Department of Statistics, University of Wisconsin-Madison [[Also Department of Forest Ecology and Management until July 1, 2006 and Department of Sociology since July 1, 2006.]]
2006-Present	Director, Methods and Statistics Subcore, Center for Demography
2008 (Fall)	Visiting Professor, Department of Statistics and Applied Probability, National University of Singapore
2001-2005	Department Chair, Department of Statistics, University of Wisconsin-Madison
1979-2005	Director, College of Agricultural and Life Sciences Statistical Consulting Facility and Biometry Program
1983-1988	Associate Professor, Department of Statistics and Department of Forest Ecology and Management, University of Wisconsin-Madison
1978-1983	Assistant Professor, Department of Statistics and Department of Forest Ecology and Management, University of Wisconsin-Madison
1977-1978	Instructor, Department of Statistics and Department of Forest Ecology and Management, University of Wisconsin-Madison



## RESEARCH

### Refereed Papers or Book Chapters in Print

- Friedrich, J.S., L.E. Schrader, and E.V. Nordheim. 1979. N deprivation in maize during grain-filling. I. Accumulation of dry matter, nitrate-N, and Sulfate-S. *Agronomy Journal* 71:461-465.
- Andrews, J.H., C.M. Kenerley, and E.V. Nordheim. 1980. Positional variation in phylloplane microbial populations within an apple tree canopy. *Microbial Ecology* 6:71-84.
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- Hirano, S. S., E. V. Nordheim, D. C. Army, and C. D. Upper. 1982. The lognormal distribution of epiphytic bacterial populations on leaf surfaces. *Applied Environmental Microbiology* 44:695-700.
- Fawole, I., W.H. Gabelman, G.C. Gerloff and E.V. Nordheim. 1982. Heritability of efficiency in phosphorous utilization in beans (*Phaseolus vulgaris* L.) grown under phosphorous stress. *Journal of the American Society for Horticultural Science* 107:94-97.
- Nordheim, E.V., A. Tsiatis, and T.J. Shapas. 1983. Incorporating extra information in experimental design for bioassay. *Biometrics* 39:87-96.
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- Andrews, J. H., F. M. Berbee, and E. V. Nordheim. 1983. Microbial antagonism to the imperfect stage of the apple scab pathogen, *Venturia inaequalis*. *Phytopathology* 73:228-234.
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- Krug, A. G., E. V. Nordheim, and R. L. Giese. 1984. Determining initial values for parameters of a Weibull model: a case study. *Forest Science* 30:573-581.
- Nordheim, E. V. 1984. Inference from nonrandomly missing categorical data: an example from a genetic study on Turner's syndrome. *Journal of the American Statistical Association* 79:772-780.
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- Guries, R. P. and E. V. Nordheim. 1984. Flight characteristics and dispersal potential of maple samaras. *Forest Science* 30:434-440.
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Research Support Summary (since 2005):

Interaction of below- and above- ground herbivory in forest gap formation: Long-term analysis of underlying mechanisms and spatio-temporal patterns, with K.F. Raffa (PI) and 6 others. NSF Ecology LTREB. <2003-2008>.

Assessment and Validation of Respondent Driven Sampling, with Giovanna Merli, 2007, UW Graduate School

Correcting for Recruiter Bias in Chain-referral Sampling of Hidden Populations. With Giovanna Merli 2008, UW Graduate School

The Development of Statistical Methodology for Census Matching. 2010. UW Graduate School

International Research Experience:

Team member -- Livestock-Natural Resource Interfaces (Latin America); participating countries: Bolivia, Ecuador, Mexico. Have developed methods of design and data monitoring; includes sustainable economics, biological conservation, and social and community development; have visited and been involved in activities in each country.

TEACHING

Formal UW Classroom Activities (since 2006-07 -- courses with primary responsibility):

Sem	Course Number	Course Description	# Students	Credits
Sp 07	Statistics 411	Intro Sample Survey Theory & Meth	18	3
Sp 07	Inter-L&S 701	Instructional Materials Development	9	2-3
F 07	Statistics 998	Statistical Consulting	7	3
Sp 08	Statistics 411	Intro Sample Survey Theory & Meth	21	3
Sp 08	Statistics 692	Teaching Statistics in the Classroom	11	1
Sp 09	Statistics 333	Applied Regression Analysis	43	3
F 09	Statistics 998	Statistical Consulting	15	3
Sp 10	Statistics 333	Applied Regression Analysis	47	3
F 10	Statistics 998	Statistical Consulting	14	3
Sp 11	Statistics 333	Applied Regression Analysis	66	3
Sp 11	Statistics 692	Teaching Statistics	12	3
F 11	Statistics 998	Statistical Consulting	14	3

(also numerous guest lectures in a variety of courses)

New Course Creation:

Statistics 571

Statistics 572

Statistics 371

Formal Teaching Activities at the National University of Singapore (Fall 2008)

Stat 5220 (similar to Stat 998 at UW) Statistical consulting 7 students  
SP1201S\_SL1 (Freshman seminar) Statistics as an Integral Part of Science and Society 15 students

Awards:

UW-Madison -- Distinguished Teaching Award (1986)

College of Agricultural and Life Sciences -- Excellence in Teaching Award (1986)

### Graduate Student Supervision

#### Doctoral Students

Richard Raubertas	(Statistics - PhD completed 1983)
Shein-Chung Chow	(Statistics - PhD completed 1985)
Mark Thornquist	(Statistics - PhD completed 1985)
Dennis Heisey	(Biometry - PhD completed 1991)
Jaekyun Lee	(Statistics - PhD completed 1995)
Kevin Gross	(Statistics & Zoology joint - PhD completed 2003; supervision joint with Prof. A.R. Ives)
Alejandro Munoz del Rio	(Statistics - PhD completed 2005)
Jialiang Li	(Statistics - PhD completed 2006; joint with Prof. C. Zhang)
Lane Burgette	(Statistics - PhD completed 2009)
Quoc Tran	(Statistics - PhD in progress; prelim completed 2011)

#### Masters Students

Hussein Mansour	(Biometry - MS completed 1979; supervision joint with Prof. J. Rutledge)
Linda Kinkel	(Biometry - MS completed 1987; supervision joint with Prof. J. Andrews)
Emilia Martins	(Biometry - MS completed 1991; supervision joint with Prof. T. Garland)
Hermanu Triwidodo	(Biometry - MS completed 1993; supervision joint with Prof. D. Hogg)
Cecilia Alstrom	(Biometry - MS completed 1993; supervision joint with Prof. H-C Kang)
Eric Espe	(Biometry - MS completed 1994; supervision joint with Prof. D. Hogg)
Ramon Dias-Uriarte	(Biometry - MS completed 1996; supervision joint with Prof. T. Garland)
Pitt Fagan	(Biometry - MS completed 1999; supervision joint with Prof. K. McSweeney)
Chunkuan Wang	(Biometry - MS completed 2002; supervision joint with Prof. S.T. Gower)
John Carew	(Biometry - MS completed 2003; supervision joint with Prof. E. Meyerand)

### Participation in Graduate Student Exams: since 2001 (excluding own students)

	MS	PhD Prelim	Phd Final
Statistics	---	8	11
Other Depts/Programs	6	18	27

#### Other International Teaching Experience:

Taught a 2-week short course (10 days; 6 hours/day) in applied statistics to 16 advanced undergraduate students in the University of Natural Science in Ho Chi Minh City, Vietnam. Jan. 2006. Instruction included hands-on computing exercises. (Instruction was in English.)

Taught a semester-long course on "Applied Statistics for the Life Sciences" at the University of Natural Science in Ho Chi Minh City, Vietnam from Aug 2010 to Jan 2011. There were 3 weeks of face-to face instruction in Vietnam in August, followed by videoconference instruction during Fall 2010, followed by one week of face-to-face instruction in Vietnam in Jan 2011. There were about 30 students, evenly divided between the mathematical and biological sciences. This was funded by a (competitive) grant from the Vietnam Educational Foundation.

#### BIOMETRY ACTIVITIES

##### Consulting:

Managed (through June 30, 2005) Statistical Consulting Facility for College of Agricultural and Life Sciences (CALS) with participation from the School of Veterinary Medicine, the Departments of Botany and Zoology within the College of Letters and Science, and the Institute for Environmental Sciences. Facility currently includes five faculty members and four graduate student project assistants. Facility assists around 300 researchers annually.

##### Biometry M.S. Program:

Created Program and shepherded it through approval process.

##### Cluster Hire Proposal:

Leader of team for development of successful "cluster hire" proposal in Molecular Biometry in Campus-wide program to recruit faculty in new important areas. Resulted in approval of three positions for mathematicians, statisticians, and/or computer scientists with strong biological interests in modeling, design, and analysis of biological systems, primarily at the molecular or cellular level.

##### Director of Biometry:

Served as leader of overall biometry efforts within CALS (through June 30, 2005). This includes above activities as well as overall guidance within CALS in statistical areas.

#### ACTIVITIES WITHIN THE SOCIAL SCIENCES

Beginning with the 2005-2006 academic year, I have been redirecting my efforts to develop increased ties between Statistics and the social science departments within L&S. Listed here are several activities to date:

I have developed a concept for and implemented a frequent Workshop series aimed at topics of joint interest to social scientists and statisticians. The format (typically) has five 90 minutes sessions scheduled approximately weekly with motivating examples, discussion of background knowledge, visits by outside experts, and wrap-up. The topics to date have been: Sp06 --- "Multiple Imputation"; F06 --- "Sampling Hidden Populations"; Sp07 --- "Propensity Scores"; F07 --- "Bayesian Model Averaging"; Sp08 --- "Hierarchical Linear Models"; Sp09 --- "Applications of Spatial Statistics"

University Service (other than departmental committees)

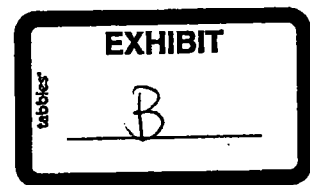
1. Campus-level
  - 1982-1983; Academic Computing Advisory Committee
  - 1987-1988; Admissions Policy Committee
  - 1986-1990; Executive Committee, Faculty Division of Biological Sciences
  - 1987-2006; Executive Committee, Biometry Masters Degree Program, Chair (several times)
  - 1990-1992; Nominations Committee, Chair 1991-92
  - 1993-1997; Recreational Sports Committee
  - 1994-1996; Committee on Committees, Chair 1995-1996
  - 1994-1999; Quantitative Reasoning Implementation Committee
  - 1998-1999; Electronic Dissertation Committee
  - 1998-2001; Faculty Rights and Responsibilities Committee
  - 1999-2003; Executive Committee for Undergraduate Biology Degree Program
  - 2000-2002; Symbiosis Committee (for coordinating chemistry, mathematics, physics, and statistics curricula for majors in biology)
  - 2009-present; ad hoc Committee on Review of Cluster Hire Program
2. College of Letters & Science
  - 2000-2004; Curriculum Committee
  - 2005; ad hoc chair of Delegated Budget Planning Committee (chair)
  - 2009-present; Academic Planning Council
3. College of Agricultural and Life Sciences
  - 1977-2006; Biometry Committee
  - 1991-2000; Member of NCR-170, Research Advances in Agricultural Statistics; organized and hosted NCR-170 Statistics in Agriculture meeting in Madison, 1994
  - 1993-1995; CALS Academic Planning Council
  - 1977-2006
4. Department of Statistics (have served on several of these committees multiple times)
  - Undergraduate Adviser
  - Graduate Admissions Committee
  - Curriculum & Degree Requirement Committee
  - Teaching Assistant Review Committee
  - Masters Exam Committee
  - New Student Advising Committee
  - Numerous ad hoc committees
  - Chair: July 1, 2001 -- June 30, 2005

Professional Service:

Elected as Council of Sections Representative to Section on Statistical Consulting Education of the American Statistical Association; 1992-1994.  
Involved with Federal Milk Market Administrators from three upper Midwest regions on project to evaluate validity of component pricing for milk; 1993-1994.  
Associate Editor for Journal of Agricultural, Biological, and Environmental Statistics; 1994-2000.  
Numerous consultancies with a range of companies including Johnson Wax, Scott's, Agracetus, and Powderject; 1977-present.  
Expert witness on two occasions with cases represented by Lawton and Cates\*.  
Expert witness for WI Dept of Justice\*

\* no depositions or appearances at a trial as an expert witness in previous four years (as of Dec 12, 2011)

# **REPORT OF ERIK V. NORDHEIM**



**December 13, 2011**

## GOALS

With the 2010 census recently completed, reapportionment must take place in Wisconsin's congressional districts. Unlike after the 2000 census, when Wisconsin lost one congressional seat, the current reapportionment effort is based on the fact that the number of congressional districts will remain at eight. (Hereafter, I will use the term district to refer to congressional district. Also, when referring to an individual district such as district 1, I will use the notation CD1.) Since the populations of each of the current districts have changed over the last 10 years by different amounts, it will be necessary for some districts to "give up" population and for others to "gain" population so as to meet legal requirements that the populations of the "new" districts are close to the same size.

The primary objective of my analysis is to tabulate and analyze the minimum population shifts required by the new census and compare those to the population shifts that would occur under the redistricting plan, in 2011 Senate Bill 149. (Hereafter, this will be referred as the proposed plan.) A secondary goal is to assess the changes in compactness of the districts under this proposed plan.

## DATA AND METHODS

The data available for this study were the 2010 census data for Wisconsin as given in the 2010 Census Redistricting Data Summary File PL 94-171. In performing my tabulation and analysis, I worked with Mr. Joel Gratz who had access to the data and the software package ESRI ArcMap 10 with the plug-in Citygate Autobound needed to perform them. The primary tabulation consisted of a determination of the population transfer from each district to each other district that implementation of the proposed plan would require. Some pairs of districts are not subject to such transfers since they are not adjacent to each other. (Thus, for example, there is no transfer between CD1 and CD8 since these districts are not adjacent.) The method for performing this tabulation is based on identifying those physical areas that would need to be moved from one district to another and determining the population of each such area. This is accomplished using the software package with plug-in mentioned above.

Using the same software, computations were conducted to determine the values for five compactness indices for each of the eight districts. This was done for the current districts as well as the proposed districts. The objective here was to determine the change in compactness from the current to the proposed districts.

## RESULTS REGARDING POPULATION SHIFTS

The first tabulation examines the population for each of the eight current districts using the 2010 census and the population of each district under the proposed plan. Also included is the net change in population. The net change is the difference between the population of the proposed district and the current district. A positive number indicates that a district needs to add population. Similarly, a negative number indicates the need to lose population. These results are presented in Table 1.

District	2010 population for district as created in 2001	2010 population for district as proposed in 2011	net change
1	728,042	710,874	-17,168
2	751,169	710,874	-40,295
3	729,957	710,873	-19,084
4	669,015	710,873	41,858
5	707,580	710,873	3,293
6	705,102	710,873	5,771
7	689,279	710,873	21,594
8	706,842	710,873	4,031

Table 1: Populations of current and proposed congressional districts using 2010 census figures.

The changes in population between 2000 and 2010 differ for each of the congressional districts created in 2001. Current districts 1, 2, and 3 have the largest current populations. District 4 has the smallest population with districts 5, 6, 7, and 8 intermediate. The proposed districts all have virtually the same populations. Indeed the populations are as close to each other as possible. The final column indicates the net change (or transference) of population that would be needed to implement the proposed plan. Thus, for example, CD1 would need to "lose" or "give up" a net population of 17,168. (These numbers can be viewed as the bare minimum shift required.)

In order to maintain jurisdictions of importance (e.g. counties, townships, census blocks) it is expected that there will need to be somewhat more transfer of population than the bare minimum. The tabulations of the actual population shifts (transfers) from each district to each other district that would result from the implementation of the proposed plan are given below in Table 2.

Current / Proposed District / District	1	2	3	4	5	6	7	8
1	686,159	3,764	NA	63	38,056	NA	NA	NA
2	1,322	633,024	0	NA	59,990	56,833	NA	NA
3	NA	74,086	539,603	NA	NA	0	<b><i>116,268</i></b>	NA
4	0	NA	NA	647,764	21,251	NA	NA	NA
5	23,393	0	NA	63,046	533,051	88,090	NA	NA
6	NA	0	20,875	NA	58,525	565,590	0	59,752
7	NA	NA	<b><i>150,395</i></b>	NA	NA	0	538,884	0
8	NA	NA	NA	NA	NA	0	55,721	651,121

Table 2: Population shifts between districts that would be required if the proposed plan were implemented.  
(NA indicates that the districts are not adjacent and hence there could be no shift.)

To interpret this table, consider the first row. This means that for the population residing in the current CD1, 686,159 would remain in CD1, 3,764 would transfer into CD2, 63 would transfer into CD4, and 38,056 would transfer to CD5. The "NA" entries in this row indicate that the other districts (3, 6, 7, 8) are not adjacent to CD1.

In some cases there are transfers in "both directions" for two adjacent districts. For example, the proposal requires a population of 3,764 to shift from CD1 to CD2 and a population of 1,322 to shift from CD2 to CD1. In some other cases the transfers are in one direction only. For example, the proposal calls for a population of 0 to shift from CD2 to CD3 whereas the required shift from CD3 to CD2 is 74,086.

The largest shifts (highlighted with bold italics) are from CD7 to CD3 and from CD3 to CD7. The required population shift under the proposed plan is 150,395 from CD7 to CD3 and 116,268 from CD3 to CD7. Thus, almost 22% ( $150,395/689,279 \times 100$ ) of the current population in CD7 will be shifted to CD3 under the proposed plan.

Table 3 provides a summary of the information in Table 2. It shows a tabulation of the total population shifted “in to” and “out of” each district. Figure 1 presents the same information in graphical form.

District	shifted in to	shifted out of	net shift (in)
1	24,715	41,883	-17,168
2	77,850	118,145	-40,295
3	171,270	190,354	-19,084
4	63,109	21,251	41,858
5	177,822	174,529	3,293
6	144,923	139,152	5,771
7	171,989	150,395	21,594
8	59,752	55,721	4,031

Table 3: Overall tabulation of population that would be transferred “in to” and “out of” each district under the proposed plan.

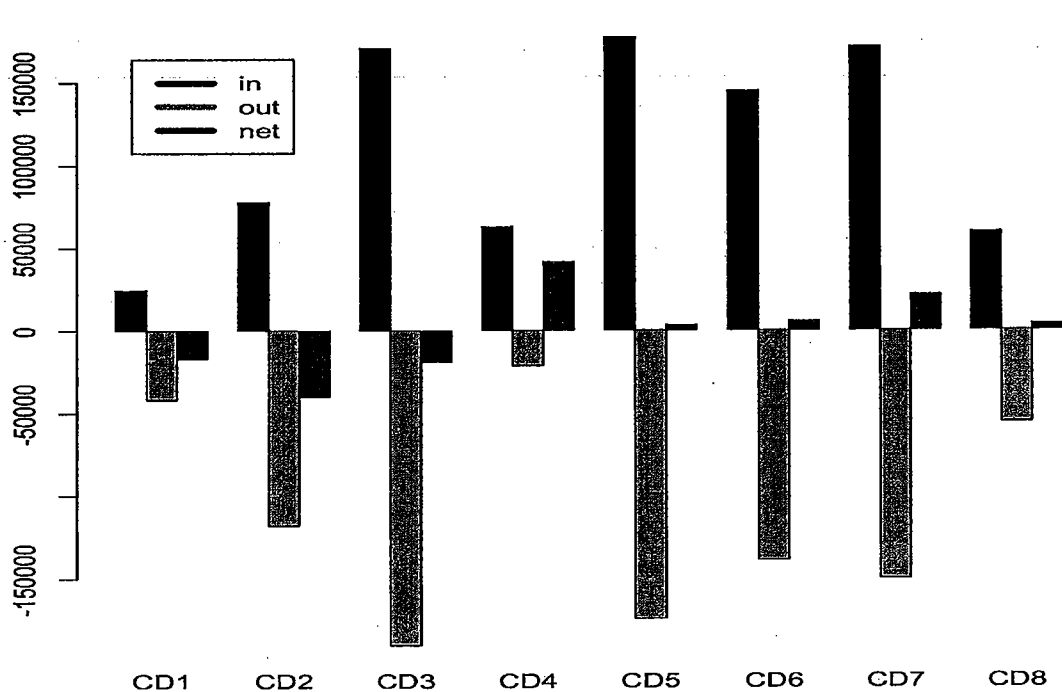


Figure 1: Graphical representation of transferred population based on Table 3.

As noted above, the net shift in Table 1 can be thought of as the minimum shift required. Also as noted above, the actual shifts are likely to be somewhat larger than these in order to respect the integrity of various jurisdictions such as counties, townships, and census blocks.

The actual proposed shifts range from somewhat above the bare minimum to well above. For example, CD4 needs to have a net of 41,858 shifted in to it. The proposed plan calls for 63,109 to be shifted in and 21,251 to be shifted out (resulting in the correct net shift). The district with the most extreme proposed shifts is CD3. Here, the "bare minimum" would be to have 19,084 shifted out of it. The proposed plan calls for 190,354 to be shifted out and 171,270 to be shifted in. The size of the population that would be shifted out is about 10 times higher than the bare minimum required.

## RESULTS RELATING TO COMPACTNESS

As I understand it, legal requirements and court cases involved in reapportionment of congressional districts indicate that districts be "compact". Qualitatively, this means that the district is not overly spread out. The difficulty is in developing a suitable measure for compactness.

The issue of compactness is one that is related to two (or more) dimensional space and is much broader than congressional or legislative districts. Indeed, compactness issues are encountered in many fields such as ecology and city planning. Many scholarly articles have been written on various aspects of compactness. There has been substantial emphasis placed on this issue by political scientists. Two articles (among many) that provide good discussions of this issue are a 2009 "White Paper" by Azavea and a frequently cited refereed paper from 1990 by Niemi et al.

I agree with the commonly expressed opinion that it is not really possible to adequately describe compactness by a single numerical index. There are too many components of district shape that allow all characteristics to be captured by a single value. Niemi et al. list more than 20 different measures and there are many others. Despite the limitations, some of these measures do provide some useful quantification of various aspects of the shape of districts. In my view, imperfect quantitative measures are better than no quantitative measures if they are interpreted with sufficient caution. It is in this spirit that I provide an analysis of compactness of Wisconsin congressional districts.

The most compact area is taken to be a circle. A circle is the shape that has the minimum perimeter for a given area and also minimizes the maximum distance between two points in the region being considered. All measures considered here will provide a compactness score of 1.0 for a perfect circle. Deviations from a perfect circle will be reflected by scores smaller than 1.0. Clearly, it is not possible for any state to be divided into circular congressional districts. Thus, virtually all actual districts will have a compactness score smaller than 1.0.

There are two primary factors that influence the compactness of a given region (district). These are the distance between the most extreme points in the region (relative to the area of the region) and the irregularity of the shape of the region, which is related to the ratio of the perimeter of a region to its area. I will refer to these as dispersion measures and indentation measures respectively. (There is potential third factor that requires taking account of the population density within a region. However, measures incorporating this third factor are much less commonly used and often require more complex computation. These will not be further considered here.)

The literature on compactness addresses the strengths and weaknesses of the various types of measures. One reason that a district may not be circular and, thus, may have a relatively large distance between its most extreme points, is that the district lies on the border of a state. All 8 of the current districts have an edge that corresponds with the state boundary and, of the proposed districts, all of them except CD5 are in this category. Some of the compactness measures are particularly sensitive to districts where the distance along one dimension is relative large. In a state like Wisconsin, such measures should be evaluated cautiously since, as noted, almost all districts have an edge at the state boundary.

The measures that are based more on indentation tend to be strongly influenced by very irregular borders. Thus, "fjord-like" or serrated structures with many indentations (such as, for example, some of the congressional districts around Chesapeake Bay) will lead to very low compactness scores. For regions (districts) with such structures, the indentation-related measures need to be regarded cautiously. However, when serrated structures are not present, the indentation-based measures appear to have considerable merit.

The Citygate Autoboard software package includes five default measures of compactness. (It also allows the user to specify other measures.) Of the default measures, three can be considered to be relatively more indentation-based and two dispersion-based. Using information from the software, these 5 measures are briefly described below. I will refer to the output of the calculations as compactness scores. (Please note that there is no inherent significance to the way I order these measures-scores.)

What seems most relevant for my analysis is not the absolute compactness scores but the changes in the scores due to the proposed reapportionment. Based on the discussion given above, there can be many reasons why the scores for some districts may differ from those of others.

Score 1: Polsby-Popper ---  $4\pi \cdot \text{area} / \text{perimeter-squared}$  (where the area and perimeter are those of the district)

Score 2: Circumference of an equal area circle divided by the perimeter of the district

Score 3: District area divided by the area of the district's convex hull.

Score 4: District area divided by the area of the minimum circle bounding the district (Reock test)

Score 5: Radius of a circle with equal area to the district divided by the radius of the smallest circle bounding the district

Table 4 provides the compactness scores for the five methods described above.

District	Score 1		Score 2		Score 3		Score 4		Score 5	
	current	proposed	current	proposed	current	proposed	current	proposed	current	proposed
1	0.28	0.29	0.58	0.58	0.90	0.88	0.23	0.24	0.48	0.49
2	0.37	0.41	0.63	0.68	0.87	0.88	0.41	0.34	0.64	0.59
3	0.36	0.17	0.63	0.42	0.76	0.59	0.19	0.25	0.43	0.50
4	0.12	0.13	0.35	0.36	0.70	0.70	0.20	0.18	0.44	0.42
5	0.24	0.24	0.51	0.50	0.73	0.82	0.24	0.32	0.49	0.57
6	0.21	0.20	0.50	0.47	0.77	0.66	0.22	0.20	0.47	0.45
7	0.18	0.15	0.45	0.41	0.76	0.68	0.29	0.24	0.54	0.49
8	0.13	0.12	0.37	0.35	0.67	0.67	0.23	0.22	0.48	0.4

Table 4: Compactness scores for five compactness measures for current and proposed districts

A comparison of the magnitudes of the different measures is not of great importance. For example, some of the scores are based on area and others on circumference or radius. (Circumference and radius have units of distance whereas area has units of the square of the distance.) What is of interest is the ranking of the districts under the various measures. Scores 1 and 2 order the districts in exactly the same manner. Similarly, scores 4 and 5 order the districts the same way. Scores 1 and 2 are very similar indentation-based measures whereas scores 4 and 5 are very similar dispersion-based measures. There are some noticeable differences between the two pairs. Score 3, which is also an indentation-based measure, tends to perform somewhat differently from scores 1 and 2.

As an example of explaining some of the differences among the scores, consider CD8. This district is affected by the irregular coastline associated with the Door Peninsula. This will almost necessarily cause indentation-based scores to be relatively low.

As noted above, it is the changes in compactness scores between the current and proposed districts that are, perhaps, of greatest interest for the current situation. These changes are tabulated in Table 5 and displayed in Figure 2.

District	Score 1	Score 2	Score 3	Score 4	Score 5
1	+ 0.01	0.00	- 0.02	+ 0.01	+ 0.01
2	+ 0.04	+ 0.05	+ 0.01	- 0.07	- 0.05
3	- 0.19	- 0.21	- 0.17	+ 0.06	+ 0.07
4	+ 0.01	+ 0.01	0.00	- 0.02	- 0.02
5	0.00	- 0.01	+ 0.09	+ 0.08	+ 0.08
6	- 0.01	- 0.03	- 0.11	- 0.02	- 0.02
7	- 0.03	- 0.04	- 0.08	- 0.05	- 0.05
8	- 0.01	- 0.02	0.00	- 0.01	- 0.01

Table 5: Compactness score differences between proposed and current districts for five compactness measures.  
(A positive score suggests that the proposed district is more compact.)

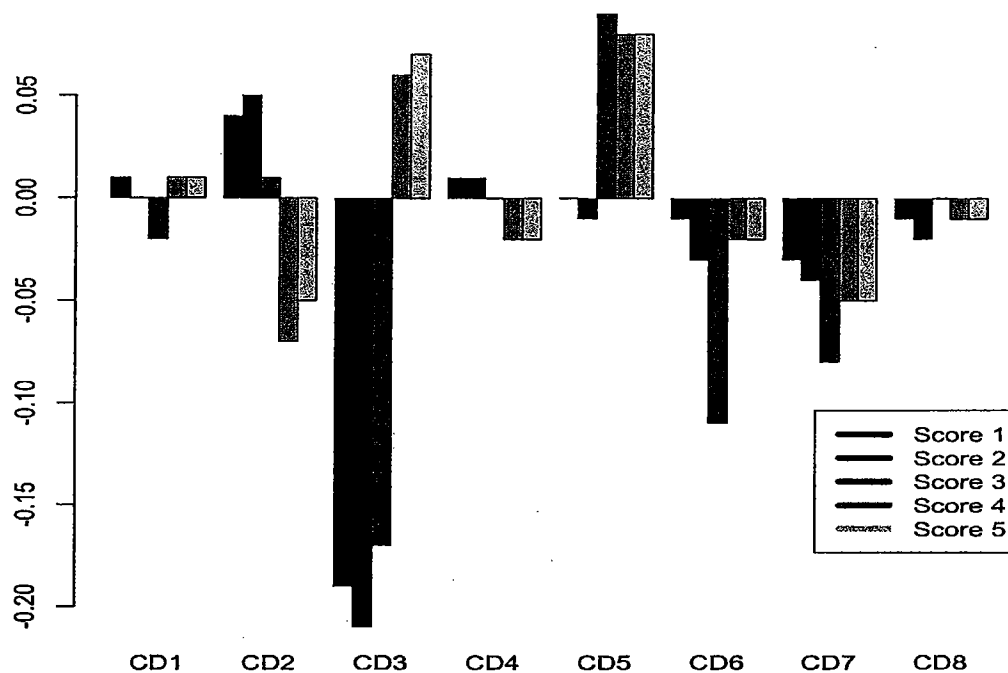


Figure 2: Graphical representation of compactness score differences based on Table 5.

The changes for scores 4 and 5 tend to be relatively small. (The largest change in magnitude is 0.08.) The decreases for CD2 and CD7 are due largely to the increased distance between the most extreme points of the district. The increases for CD5 and CD3 are due to a corresponding decreased distance. However, in all cases the changes are quite modest.

The changes in scores 1 and 2 are similarly relatively small except for CD3 for which there is a sizable decrease in compactness. This is due to the "U-shaped" northern portion of the proposed district. This "U-shape" substantially increases the ratio of the perimeter to the area which is the factor to which scores 1 and 2 are most responsive. Score 3 is similar to scores 1 and 2 although it performs somewhat differently from the other two.

Thus, there is some notable evidence that the proposed CD3 would result in a district that is considerably less compact (using indentation-based measures) than is the case with current CD3. Since the proposed changes in the border of CD3 involve very little of the serrated structures (like those in Chesapeake Bay), I believe that the methods underlying scores 1, 2, and 3 are valid ones for explaining the change in compactness.

## CONCLUSIONS

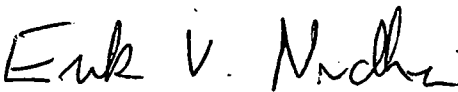
I summarize my key findings as follows:

1. The proposed plan results in the transference of population substantially in excess of the minimum transference required. The two largest inter-district population transfers are from CD7 to CD3 and from CD3 to CD7.
2. The proposed plan for CD3 results in a considerable decrease in compactness (as measured by indentation-based measures). The proposed plan will have relatively smaller effects on the other districts.

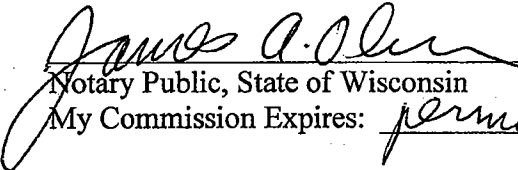
### References:

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Niemi, R.G., B. Grofman, C. Carlucci, and T. Hofeller. 1990. Measuring compactness and the role of a compactness standard in a test for partisan and racial gerrymandering. The Journal of Politics 52:1155-1181.

  
ERIK V. NORDHEIM

Signed and sworn before me  
this 14 day of December 2011.

  
Notary Public, State of Wisconsin  
My Commission Expires: permanent

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**Eastern District of Wisconsin**

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